Intl. Trans. in Op. Res. 10 (2003) 543–545

INTERNATIONAL TRANSACTIONS IN OPERATIONAL RESEARCH

IFORS' Operational Research Hall of Fame
Richard Ernest Bellman

The creator of dynamic programming.

Born: 26 August, 1920, New York City, New York, USA

Died: 19 March, 1984, Los Angeles, California, USA

Education: B.A. Mathematics, 1941, Brooklyn College; M.A. Mathematics, 1943, University of Wisconsin; PhD. Mathematics, 1946, Princeton University

Academic and research positions: Assistant Professor of Mathematics, Princeton University (1946–48); Associate Professor of Mathematics, Stanford University (1948–52); Research Mathematician, The RAND Corporation (1953–65); Professor of Mathematics, Electrical Engineering and Medicine, University of Southern California (1965–84)

Awards: First Norbert Weiner Prize, Applied Mathematics (American Mathematical Society and the Society for Industrial and Applied Mathematics) (1970); First Dickson Prize (Carnegie-Mellon University) (1970); ALZA Distinguished Lectureship (Biomedical Engineering Society) (1973); Fellow (American Academy of Arts and Sciences) (1975); John Von Neumann Theory Award (Institute for Operations Research and the Management Sciences) (1976); Member (National Academy of Engineering) (1977); Gold Medal for Dynamic Programming (IEEE) (1978); Fellow (Society for Mathematical Biology) (1980); Member (National Academy of Sciences) (1983); Heritage Medal (American Council for Control) (1983)

Richard Ernest Bellman was born August 26, 1920 in New York City, the son of John James Bellman and Pearl Saffian Bellman. He attended Abraham Lincoln High School in Brooklyn, New York, where he was on the mathematics team and became the "top man" in New York City during his senior year – no small accomplishment in a large city, known for its excellent schools

and bright, highly competitive students. In January 1937 at the age of 16 he entered the City College of New York with the intention of becoming a theoretical physicist. A year later he transferred to Brooklyn College and majored in mathematics. In his junior and senior years he was a member of the three-person team representing Brooklyn College that won the William Lowell Putnam mathematical competition for all colleges in the United States and Canada.

Bellman entered graduate school at Johns Hopkins University in Baltimore, Maryland in September 1941, just as America became involved in the war. He left there to become an instructor of military electronics at the University of Wisconsin later that academic year, teaching electronics while earning a Masters Degree in mathematics. During 1943–44 he taught in the Army Specialized Training Program at Princeton University and continued his graduate studies in mathematics. He thereby avoided being drafted by performing patriotic service. He was finally drafted in December 1944 and sent to Los Alamos where he worked in theoretical physics for the Manhattan A-bomb project until his discharge in 1946.

In that year Bellman returned to Princeton and completed his doctoral work with a dissertation on the stability theory of differential equations under Professor Solomon Lefschetz. He remained at Princeton as an Assistant Professor until 1948, when he left to become a tenured Associate Professor at Stanford University at the age of 28, despite having lost several years of formal education during World War II. Bellman spent the summer of 1948 at the RAND Corporation where he became fascinated by the many practical uses of mathematical modeling to which he was exposed. After an additional visit to RAND during the following summer, when he became interested in multistage decision processes, and a year on leave from Stanford to pursue H-bomb research at Princeton, Bellman decided to leave Stanford for full-time employment at RAND in 1952. The challenges of the real world won out over the cloistered academic environment. By now he had published, either individually or jointly, over fifty papers on a large variety of mostly theoretical mathematical topics.

His initial interests at RAND were dynamic programming (the name he coined for the study of the functional equations associated with the optimization of multistage decision processes), variational (optimal control) theory, and differential-difference (time-lag) processes. His first dynamic programming publication "On the Theory of Dynamic Programming" appeared in 1952 in the *Proceedings of the National Academy of Sciences* (USA), where he also published as joint author his first paper on variational problems in 1953. In 1954 he elaborated and extended a paper he had first published in 1949 on the "Existence and Boundedness of Solutions of Nonlinear Differential-Difference Equations" into a book-length RAND report on time-lag problems.

By 1954 Bellman's attention had turned toward stochastic decision problems. In 1957, in a paper in the *Journal of Mathematics and Mechanics*, he introduced the topic of Markovian Decision Processes and solution by iteration in policy space. The following year he first published on stochastic control processes, with many further papers to come. The "Bellman Equation" is central to the study of this topic.

Bellman created or extended many other fields of applied mathematics not conventionally associated with operational research. He played a leading role in introducing invariant imbedding, essentially dynamic programming methods applied to situations descriptive of natural processes lacking an optimization aspect. He employed invariant imbedding to analyze neutron transport and radiative transfer problems. Interest in transfer problems led him to mathematical biology with an emphasis on modeling chemical transfer occurring during cancer chemotherapy.

When Bellman left RAND in 1965 to join the faculty of the University of Southern California, it is not surprising to find him designated Professor of Mathematics, Electrical Engineering and Medicine.

In 1973, at the age of 53, while he was still at the height of his mathematical powers, he was crippled by post-surgical complications following the removal of a brain tumor. Despite almost total physical disability, his mind remained as active and alert as ever and almost 100 Bellman papers appeared after this unfortunate event. His heart, presumably overtaxed by coping with his physical disabilities, gave out on March 19, 1984.

Bellman was intrigued by, and wrote about, mathematical approaches to artificial intelligence. Unfortunately, he failed to live to see dynamic programming become the basis in the 1980s of a major research paradigm in machine learning called, variously, temporal difference reinforcement learning, neuro-dynamic programming, or approximate dynamic programming. Neuroscientists have even reported evidence that the animal brain learns in situations requiring sequential actions to construct an approximation to the optimal value function of dynamic programming.

Richard Bellman saw mathematics as a tool to be used in the service of humanity. The vast majority of his 619 published papers and 39 books involve using this discipline with exceptional skill and imagination to produce understanding and, when possible, control of an amazing variety of natural and synthetic processes.

Stuart Dreyfus

Selected original works

Bellman, R.E., 1952. On the theory of dynamic programming. *Proceedings of the National Academy of Sciences* 38, 716–719.

Bellman, R.E., 1953. Dynamic programming and a new formalism in the calculus of variations. *Proceedings of the National Academy of Sciences* 39, 1077–1082.

Bellman, R.E., 1954. Survey of the Mathematical Theory of Time-Lag Retarded Control. Rand Report No. R-256.

Bellman, R.E., 1957. *Dynamic Programming*. Princeton University Press, New Jersey.

Bellman, R.E., 1957. Markovian decision processes. *Journal of Mathematics and Mechanics* 38, 716–719.

Bellman, R.E., 1957. A Markovian decision process. *Journal of Mathematics and Mechanics* 38, 679–684.

Bellman, R.E., 1958. Dynamic programming and stochastic control processes. *Information and Control* 1, 228–239.

Bellman, R.E., 1968. *Introduction to the Mathematical Theory of Control Processes 1*. Academic Press, New York.

Bellman, R.E., 1971. *Introduction to the Mathematical Theory of Control Processes 2*. Academic Press, New York.

Bellman, R.E., Wing, G.M., 1975. *An Introduction to Invariant Imbedding*. John Wiley & Sons, New York.

Roth, R.S. (ed.), 1986. *The Bellman Continuum*. World Scientific Publishing Company, Singapore.

Biographical material

Bellman, R.E., 1984. *Eye of the Hurricane: an autobiography*. World Scientific Publishing Company, Singapore.